

ORIGIN AND REACTIVITY OF THE MARTIAN SOIL: A 2003 MICROMISSION

Albert S. Yen¹ (ayen@mail1.jpl.nasa.gov), S. Sam Kim², John Marshall³, and Bruce C. Murray⁴

¹ Jet Propulsion Laboratory, Mail Stop 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109

² Jet Propulsion Laboratory, Mail Stop 183-401, 4800 Oak Grove Drive, Pasadena, CA 91109

³ SETI Institute at MS 239-12, NASA Ames Research Center, Moffett Field, CA 94035

⁴ California Institute of Technology, 150-21, 1200 E. California Blvd., Pasadena, CA 91125

Scientific Objectives

The role of water in the development of the martian surface remains a fundamental scientific question. Did Mars have one or more “warm and wet” climatic episodes where liquid water was stable at the surface? If so, the mineral phases present in the soils should be consistent with a history of aqueous weathering. More generally, the formation of hydrated mineral phases on Mars is a strong indicator of past habitable surface environments. The primary purpose of this investigation is to help resolve the question of whether such aqueous indicators are present on Mars by probing the upper meter for diagnostic mineral species.

mineralogy

According to Burns [1993], the formation of the ferric oxides responsible for the visible color of Mars are the result of dissolution of Fe²⁺ phases from basalts followed by aqueous oxidation and precipitation of Fe³⁺ mineral assemblages. These precipitates likely included iron oxyhydroxides such as goethite (α -FeOOH) and lepidocrocite (γ -FeOOH), but convincing evidence for these phases at the surface is still absent. The stability of these minerals is enhanced beneath the surface [Pollack *et al.*, 1970], and thus we propose a subsurface search for hydroxylated iron species as a test for a large-scale chemical weathering process based on interactions with liquid water.

It is also possible that the ferric minerals on Mars are not aqueous alteration products of the rocks. A chemical study of the Pathfinder landing site concluded that the soils are not directly derived from the surrounding rocks and are enhanced in Mg and Fe [Rieder *et al.*, 1997]. The additional source of these elements might be from other regions of Mars and transported by winds, or alternatively, from exogenic sources. Gibson [1970] proposed that the spectral reflectivity of Mars is consistent with oxidized meteoritic material. Yen and Murray [1998] further extend Gibson's idea and show, in the laboratory, that metallic iron can be readily oxidized to maghemite and hematite under present-day martian surface conditions (in the absence of liquid water). A test for a meteoritic component of the soil can be conducted, as described below, by searching for the presence of Ni at the martian surface. The average abundance of nickel in an Fe-Ni meteorite is ~7% and, if present at measurable levels in the soil, would be indicative of an exogenic contribution. In addition, it may be possible to directly search for mineral phases common in meteorites.

An understanding of the formation and evolution of the martian soil would not be complete without addressing the unusual reactivity discovered by the Viking Landers [Oyama and Berdahl, 1977; Levin and Straat, 1977]. The presence of an inorganic oxidant, possibly one produced as a result of photochemical processes, is the most widely accepted explanation of the Viking results. Are these chemical species simply adsorbed on soil grains, or have they reacted with the metal oxide substrates and altered the mineral structures? Could a completely different (non-photochemical) process be responsible for the soil reactivity? The various ideas for the nature of this putative oxidant could be constrained by a measurement of the change in reactivity with depth. Different compositions will have different lifetimes and mobilities and thus will have different vertical profiles. Because the oxidizing compounds are believed to actively destroy organic molecules, determination of the reactivity gradient also has significant implications for the search for life on Mars.

Implementation Approach

The most practical method for conducting the scientific investigations of the soil as described above for a 2003 micromission is by making modifications to the existing Deep Space 2 (DS2) microprobe design. DS2 micropenetrators are unique in their ability to provide easy access to subsurface samples. The current system is capable of penetrating to a depth of approximately 50 cm but can be readily modified to achieve depths of 1 meter or more. The other major change to the existing system would be a redesign of the telecommunications system so an efficient link to a relay orbiter can be established. The instrument complement we envision for this 2003 micromission includes a ^{57}Fe nuclear magnetic resonance (NMR) spectrometer to characterize iron minerals and to specifically look for oxyhydroxide phases, an X-Ray fluorescence (XRF) device to look for Ni in the soil, thin-film chemiresistors in the forebody and aftbody of the probe to measure the soil reactivity gradient, and possibly an X-Ray powder diffraction (XRD) instrument to search for signatures of exogenic minerals.

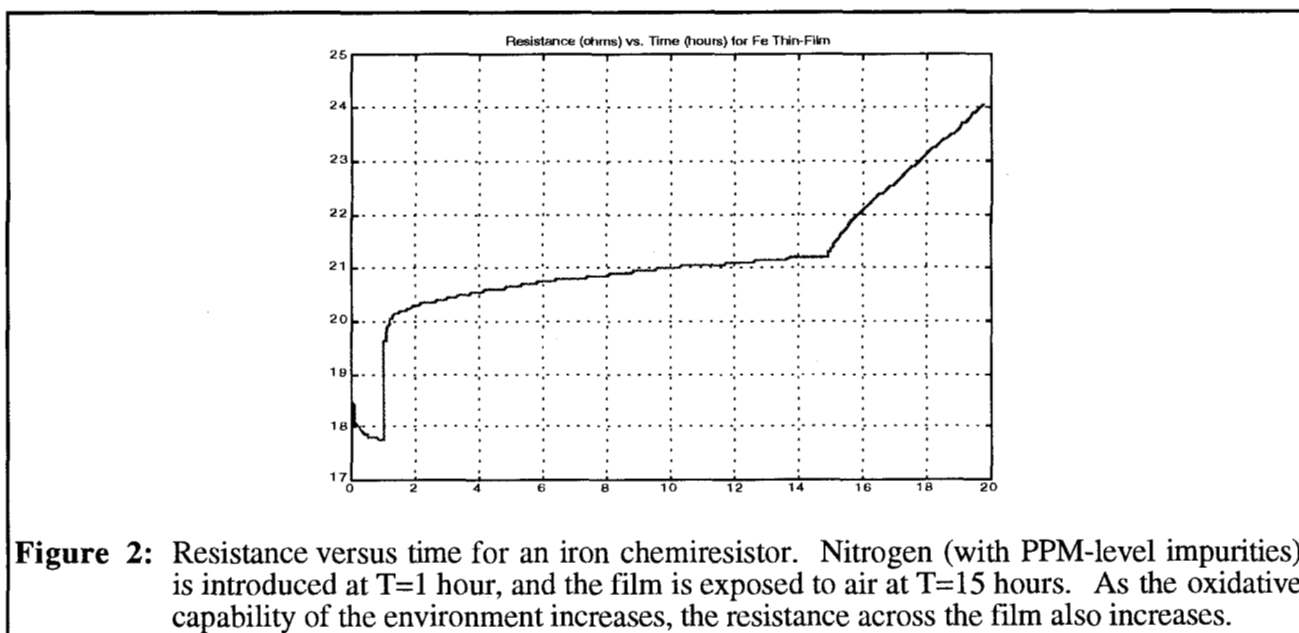
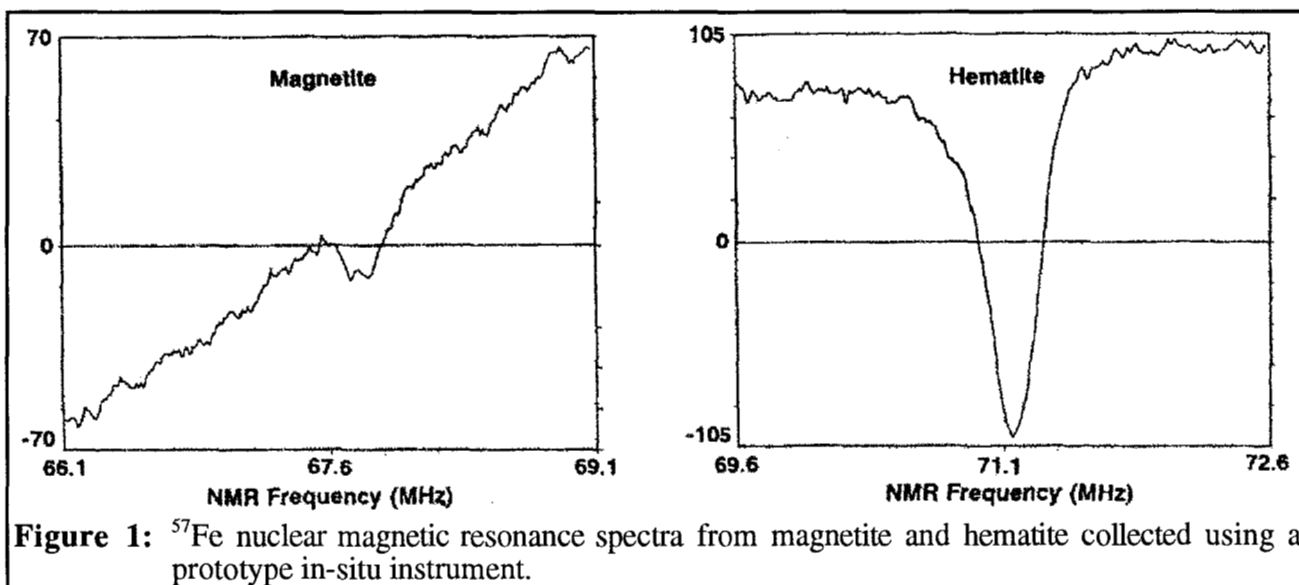
The NMR would be housed in the forebody to sample soils at depth that remain unaltered by the surface environment. Detection of iron minerals is accomplished by transmitting radio frequencies through a small window and looking for characteristic absorptions. An additional sensor and collecting magnet would be placed on the aftbody to identify the magnetic particles in the windblown materials. Figure 1 shows initial results from a 50 gram prototype instrument operating on a 9 volt battery. Work is ongoing to determine the absolute sensitivity limits of the device to the plausible iron oxides and oxyhydroxides on Mars.

Modifications to an X-Ray instrument concept [Marshall *et al.*, 1996] to be compatible with the DS2 constraints may be possible and may permit direct measurements of the Ni abundance in the martian soil. The basic instrument would be capable of making a calibrated X-Ray fluorescence measurement and would be carried in the aftbody of the probe. We are currently investigating the possibility of carrying a complete XRF/XRD instrument in the aftbody to characterize the mineralogy and to look more thoroughly for the signature of exogenic material.

Recent work with thin-film metallic chemiresistors has demonstrated the ability to sensitively measure small changes in oxidizing potential [Yen, 1998]. Metals are good conductors when unreacted, and insulators when oxidized to any of the stable oxides. Thin layers (~ 100 Å) of metal rapidly exhibit dramatic resistance changes when small fractions of a monolayer of metal are converted to metal oxide (see figure 2). An array of chemiresistors in the forebody can be compared to a similar set in the aftbody to characterize the reactivity changes with depth. In addition to this gradient information, the rate of oxidation of the different thin-films in the array can provide constraints on the composition of the oxidizing species.

Summary

A DS2-based microprobe system can be instrumented for a 2003 micromission to investigate the origin and reactivity of the martian soil. These measurements would provide invaluable information regarding the climate history and exobiological potential of the planet. The NMR, X-Ray, and chemiresistor measurement approach described here embodies a highly synergistic and general set of soil interrogation methods for elements, compounds, and crystal structures and can also be applied to other geologic questions of interest. For example, if the capability for precise targeting of the probes is available, then in-situ investigations of suspected evaporite and hydrothermal deposits would be possible with the same set of instruments.



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